

Evidence of Planetesimal infall on to the very young Herbig Be star LkH $_{\alpha}$ 234¹

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ABSTRACT

We report here the first evidence for planetesimal infall onto the very young Herbig Be star LkH $_{\alpha}$ 234. These results are based on observations acquired over 31 days using spectroscopy of the sodium D lines, the He I 5876Å, and hydrogen H $_{\alpha}$ lines. We find Redshifted Absorption Components (RAC) with velocities up to 200 km/s and very mild Blueshifted Absorption Components (BEC) up to 100 km/s in the Na I lines. No correlation is observed between the appearance of the Na I RAC & BEC and the H $_{\alpha}$ and He I line variability, which suggests that these (Na I RAC & BEC) are formed in a process unrelated to the circumstellar gas accretion. We interpret the Na I RAC as evidence for an infalling evaporating body, greater than 100 km in diameter, which is able to survive at distances between 2.0 to 0.1 AU from the star. The dramatic appearance of the sodium RAC and mild BEC is readily explained by the dynamics of this infalling body making LkH $_{\alpha}$ 234 the youngest (age ~ 0.1 Myr) system with evidence for the presence of planetesimals.

Subject headings: stars: formation — stars: pre-main-sequence — circumstellar matter — stars: individual (LkH $_{\alpha}$ 234)

1. Introduction

LkH $_{\alpha}$ 234 ($m_v=11.9$ mag) is a star embedded in a nebula associated with the NGC 7129 star forming region and is at a distance of about 1250 parsecs. This is one of the youngest known Herbig Be objects and has an age ~ 0.1 million years and spectral type of B5 (Fuentes et al. 2001). Herbig Ae/Be stars are intermediate mass (2 to 10 M_{\odot}) pre-main-sequence stars (Herbig 1960). A number of Herbig Ae stars have been found to possess circumstellar disks and show both photometric and spectroscopic variability (Herbst et al. 1999). LkH $_{\alpha}$ 234 though much hotter and more massive also exhibits these properties (Fuentes et al. 2001, Herbst et al. 1999, Polomski et al. 2002). The star shows photometric variability of 1.2 mag-

nitude in the V band and is known to possess a circumstellar disk with the disk mass to the stellar mass ratio (M_D/M_*) ≤ 0.02 . A detailed description of LkH $_{\alpha}$ 234 and its circumstellar region can be found in Fuentes et al. (2001, and references therein).

Spectroscopic variations in metallic lines (like Na I, Ca II, etc.) in young A type stars like β Pictoris (20 to 100 million years) are often interpreted as the signature of star grazing comets or falling evaporating bodies with sizes of tens of kilometers (Grinin et al. 1996, Smith & Terrile 1984, Thebault & Beust 2001). The only Herbig Be star where grazing cometary transient events have been inferred so far is HD 100546 (Viera et al. 1999). However, HD100546 is much older (≥ 10 Myrs) and cooler (spectral type $\sim B9$) compared to LkH $_{\alpha}$ 234. High resolution spectroscopic monitoring of very young (0.1 to 1 Myrs) Herbig Be stars are scanty

¹Based on observations from the 9.2m Hobby-Eberly Telescope

and uncharted.

Here we report dramatic variations in the spectroscopic lines of Na I 5890Å(D2), and 5896Å(D1), He I 5876Å, and H_α of LkH α 234 over a period of 31 days during Oct.-Nov. 2003. The observations consists of high resolution spectra ($R=30,000$) from the Hobby-Eberly Telescope (HET) using the High Resolution Spectrograph (HRS). Section 2 describes observations and in section 3 we discuss the results and section 4 gives the conclusion.

2. Observations

We have obtained high signal to noise ratio and high resolution spectra ($R=30,000$, $\sim 0.2\text{\AA}$) of LkHa234 covering He I 5876Å, Na I D2 & D1 lines and the Balmer H_α at 6563Å. The observations were taken with the 9.2m Hobby-Eberly Telescope (HET) (Ramsey et al. 1998) using its High Resolution Spectrograph (HRS) (Tull 1998). The echelle spectral orders were optimized to cover the wavelength range between 5700 to 6750Å. This allowed the spectral lines of interest to be recorded by the “blue” CCD of the spectrograph that has fewer number of bad pixels than the “red” CCD. The results comprise of five data sets over a time period of 31 days. The observation dates were: 7th, 13th, 23rd, 27th October and 8th November 2003. On each night of observation, three ten minutes exposures on LkH α 234 were taken which were combined to get high signal to noise ratio ($S/N = 70$ to 100). All data were reduced using standard IRAF routines under ECHELLE tasks. Every spectrum was bias subtracted, and flat-fielded. Spectral Calibrations were done using Thorium-Argon lamp spectra taken either immediately before or after the observations. We found that the wavelength calibration is accurate up to 0.05Å.

H_α (6563Å), He I 5876Å, and Na I D2 & D1 spectral lines are shown in figures 1 and 2 respectively and the dates of observations are noted along side of the spectra. The x-axis is in terms of relative velocity (km/s) with respect to the center of the lines in the stellar rest frame and the y-axis shows line intensities normalized with respect to the stellar continuum. In figure 2 the zero of the relative velocity scale is with respect to the stellar rest frame of the sodium D2 line.

3. Results & Discussion

3.1. Gaseous accretion

We illustrate in figure 1 the variability in H_α and He I lines. These are seen as stellar photospheric absorption lines in the spectra observed on 7th Oct. 2003. However, in all the later days of observations the H_α appeared to be in emission consisting of two components, the Red shifted Emission Component (REC), and the Blue shifted Emission Component (BEC). The H_α equivalent width varied from +3Å(on 7th Oct.) to -50Å(13th Oct.) in just 6 days and it continued to rise up to -100Å(27th Oct.) before it decayed to -74Å(8th Nov.). The relative velocity between the REC and BEC varied between 150 km/s to 225 km/s with the REC stronger than the BEC by a factor of 2.5 to 3.5.

The spectra obtained on 7th Oct. 2003 do not show any sign of emission or activity in H_α or He I. This observation shows the star in a quiescent state, with neither accretion nor stellar wind affecting the absorption line profile. The variations in the He I line are found to correlate with the variations in the H_α . Whenever the H_α BEC and REC are stronger the He I either fills up due to mild emission or shows a very large absorption width (almost 1.7 times the photospheric line width). The line width varied from 150 km/s to 260 km/s. A B5 star does not have sufficiently energetic photons to ionize He I (Jaschek & Jaschek 1995), so the filling up of the He I absorption line due to mild emission is an indicator of accretion phenomena (de Winter et al. 1999). We find the disk luminosity to be about 1% of the stellar luminosity ($L_* \sim 10^3 L_\odot$) with maximum disk temperature of $\sim 21000\text{K}$, if we consider an accretion rate of $10^{-7} M_\odot$ per year (Natta et al. 2000).

Therefore, the double peak H_α (REC & BEC) profiles and the He I mild emission are because of orbiting accreting gas on to the star and as well as outflow of circumstellar gas (BEC in H_α due to accretion heat). However, when the accretion luminosity is not strong enough to produce enough ionizing photons, the He I line appears as a very broad absorption feature. The broad absorption feature is the effect of the combination of the stellar photospheric line and various unresolved circumstellar gas components corresponding to REC and BEC of H_α .

The effect of gaseous accretion are probably also seen on the nebular emission lines. We found a correlation between the total equivalent width in H_α and the peak nebular emission in H_α and Na I. Figures 1 & 2 show that the nebular H_α and Na I lines were of minimal intensity (~ 1.06 above the continuum) on 7th Oct. The same lines are strongest ($H_\alpha \sim 7.9$, on the blue wing of the REC, and Na I D2 line ~ 3.0) on 27th Oct. when the H_α equivalent width is maximum ($\sim 100\text{\AA}$). We plan to model the impact of the episodic accretion on the nebula using a photo-ionizing code (for eg. the Cloudy code) which will be published along with the entire spectra of LkH $_{\alpha}$ 234 elsewhere in the near future.

3.2. Planetesimal infall

Figure 2 shows the variability in the Na I D2 and D1 lines. Redshifted Absorption Components (RAC) were observed in Na I lines on only one night (13 Oct. 2003) with a maximum redshifted velocity of 200 km/s. The RAC's associated with both the Na I lines are of similar depth (for redshifts $\leq 100\text{km/s}$) which is an indicator of saturation (unshielded Na I column density = $10^{12}/\text{cm}^2$) (de Winter et al. 1999). However, the maximum depth of these components is about 30% of the stellar continuum implying partial coverage of the stellar photosphere. In addition to Na I RAC, very mild BEC (60 to 100 km/s and 1.05 to 1.07 above the continuum) are also seen on the 13th Oct. spectra. The variations in He I and H_α are observed even when no Na I RAC & BEC are seen (see figures 1 & 2). Thus the appearance and disappearance of the Na I RAC & BEC are uncorrelated with the variations in H_α and He I line profiles. We conclude that we witnessed a transient phenomenon on 13th Oct. 2003 whose effects lasted a few days at most.

From the Keplerian dynamics of an infalling object (Beust et al. 2001) the most redshifted Na I absorption component velocity (200 km/s) should correspond to a distance of 0.1 AU from the star. At this distance both the number of ionizing photons and intensity of the stellar wind will be too high for any unshielded Na I to survive (Sorelli et al. 1996). Their calculations using photo-ionizing codes under local thermodynamical equilibrium (LTE) and non-LTE show that only a solid body like a comet or asteroid can approach a

hot star this close before it disintegrates and evaporates. Further, theoretical model calculations for stars up to B9 show that the size of solid bodies which are able to survive up to a distance of 0.1 AU should be at least 100 km in diameter (Beust et al. 2001). The mild Na I BEC could then be part of the falling evaporating body being blown away by the stellar wind or radiation pressure. However, this will also mean that the falling solid body may have a high eccentric orbit so that the blown away material is not projected against the stellar surface. Our Na I RAC and BEC observations are consistent with such an object dissociating between 2 AU and 0.1 AU from the B5 star LkH $_{\alpha}$ 234.

In many Herbig Ae stars, variations in Na I RACs and BAC's usually correlates with H_α and He I variations (de Winter et al. 1999, Grinin et al. 1996). Such Na I variations are now thought to be generated by magneto-hydrodynamic funnelling of neutral gas on to the star rather than solid body infall (Beust et al. 2001, Mora et al. 2002, Natta et al. 2000). No such correlation is present in the current LkH $_{\alpha}$ 234 data set. Of particular significance is the observation on 27th Oct. 2003 when the REC and BEC of H_α are the strongest. The absence of any Na I RAC and BEC in this observation is a strong argument against the Na I line variations being caused by neutral matter funnelled onto the star by magnetic fields. The variability of H_α and He I in LkH $_{\alpha}$ 234 are due to episodic gas accretion, while the observed variations in Na I lines is a transient event that exhibits the dynamical signature of a body (≥ 100 km in diameter) falling onto the star. It is worth mentioning here that recent studies on meteors from cometary origin by Trigo-Rodriguez et al. (2004) have shown greater sodium abundances than those expected for interplanetary dust particles and chondritic meteorites and Potter et al. (2002) have detected comet like sodium tail from planet Mercury, and also the discovery of presence of sodium tail in comets (Cremoneese et al. 1997). Thus an infalling solid body of asteroid size and deficient in H can produce the observed Na I RAC and BEC and no correlation with the H and He I lines.

The dusty circumstellar disk of the young star LkH $_{\alpha}$ 234 could be a newly formed protoplanetary disk consisting of solid bodies of different sizes (Fuente et al. 2001). Theoretical models of for-

mation of planetary bodies in circumstellar disks around a $1M_{\odot}$ mass star show that planetesimals of sizes of up to a few hundred kilometers can quickly form within the first 10^5 years and the typical cumulative number of such bodies can be 10^4 to 10^6 between 0.5 to 1.5 AU from the star (Lissauer 1993, Weidenschilling et al. 1997). While such numbers are not known for B type stars, LkH $_{\alpha}$ 234 (age ~ 0.1 Myrs) may have high frequency of infall events (Grady et al. 2000).

4. Conclusion

We have presented here high resolution spectroscopic monitoring of a Herbig Be star LkH $_{\alpha}$ 234 in the Na I (D2&D1), He I (5876Å) and H $_{\alpha}$ lines. We found no correlations between the Na I and the He I and H $_{\alpha}$ line variability in the five data sets over a period of 31 days (7th Oct. 2003 to 8th Nov. 2003) though we do find a correlation between He I and H $_{\alpha}$. Thus the origin of variation in the Na I line (RAC up to 200 km/s and BEC up to 100 km/s seen only on 13th Oct. 2003) is different from those of H $_{\alpha}$ and He I. While the H $_{\alpha}$ and He I line variations are due to episodic gaseous accretion, the Na I RAC indicate a dramatic transient event of solid body infall on to the star and the BEC as the blown away parts of the solid body not projected against the stellar surface. Considering the Keplerian dynamics and the harsh environment of a B5 star, we estimate that a solid body of size ≥ 100 km broke up and disintegrated at a distance between 0.1 to 2.0 AU from the star. This makes LkH $_{\alpha}$ 234 the youngest system (~ 0.1 Myrs) with evidence for protoplanetary bodies of asteroidal size. We plan to pursue further spectroscopic monitoring of the star with the HET to determine the frequency of such events and further understand the complicated dynamics of this very young circumstellar environment.

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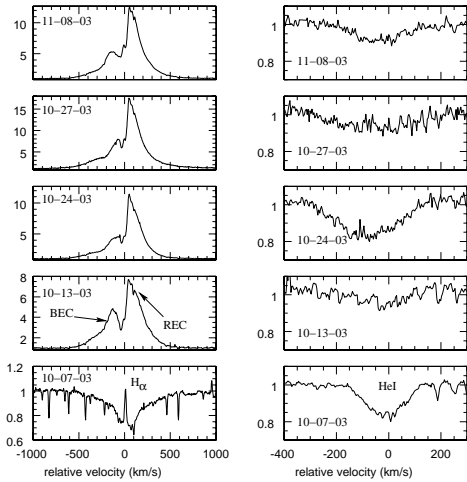


Fig. 1.— The left panel shows the spectra of LkH α 234 around the H α (6563 Å) emission line and the right panel around HeI (5876 Å). The x-axis is in relative velocity with respect to the rest wavelengths of H α and HeI respectively. The y-axis is the flux normalised with respect to the stellar continuum. The dates of observations are shown with each spectrum. The narrow 20 km/s width nebular H α emission line is seen near the core of the stellar photospheric absorption line on 10-07-03 and so are many nebular absorption lines. The nebular H α line can also be seen on the blue wing of the REC on the other dates of observations.

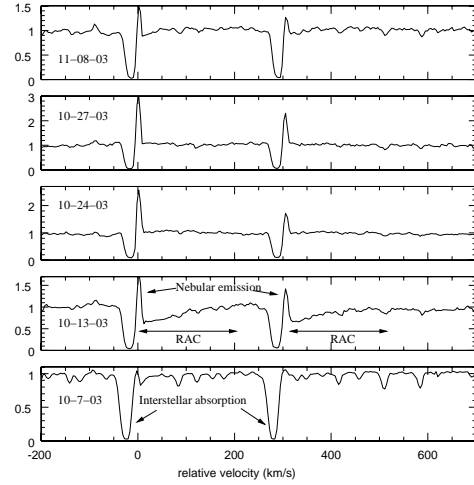


Fig. 2.— The spectra of LkH α 234 in the region of Na I D2 (5890 Å) and D1 (5896 Å) absorption features. The x-axis has been converted into relative velocity (km/s) with respect to the Na I D2 line at the stellar rest frame. The y-axis is same as in figure 1. The Red shifted Absorption Components (RAC), the nebular emission and the interstellar absorption lines are marked. The dates of observations are shown along with each spectrum. Also seen are the very mild Blueshifted Absorption Components (BEC; on 10-13-03) on the blue side of the Na I (D2&D1) interstellar absorption lines. The interstellar Na I lines are offset by 27 km/s from the rest frame of the star.